

(10) **Patent No.:** US 9,456,268 B2
(45) **Date of Patent:** Sep. 27, 2016

- (58) **Field of Classification Search**

- CPC H03H 21/0012; H04R 25/70; H04R
25/356; H04R 25/407; H04R 25/453; H04R
25/502; H04R 25/505; H04R 25/554; H04R
2225/41; H04R 2225/43; H04R 2430/03

- USPC 381/312, 317, 318
See application file for complete search history.

- (56)
- References Cited**

- U.S. PATENT DOCUMENTS

- | | | | |
|-----------|---|---------|---------|
| 3,987,245 | A | 10/1976 | Fasen |
| 4,837,832 | A | 6/1989 | Fanshel |
| 5,430,826 | A | 7/1995 | Webster |
| 5,867,581 | A | 2/1999 | Obara |

- (Continued)

- ## OTHER PUBLICATIONS

- (65) **Prior Publication Data**

Office Action for U.S. Appl. No. 12/017,878, filed Jan. 22, 2008,
mailed Jan. 18, 2012.

- US 2014/0219462 A1 Aug. 7, 2014

(Continued)

Related U.S. Application Data

Primary Examiner — Brian Ensey

- (63) Continuation of application No. 12/165,022, filed on Jun. 30, 2008, now Pat. No. 8,718,305.

(74) *Attorney, Agent, or Firm* — Pablo Meles

- (60) Provisional application No. 60/946,834, filed on Jun. 28, 2007.

(57) **ABSTRACT**

- (51) **Int. Cl.**

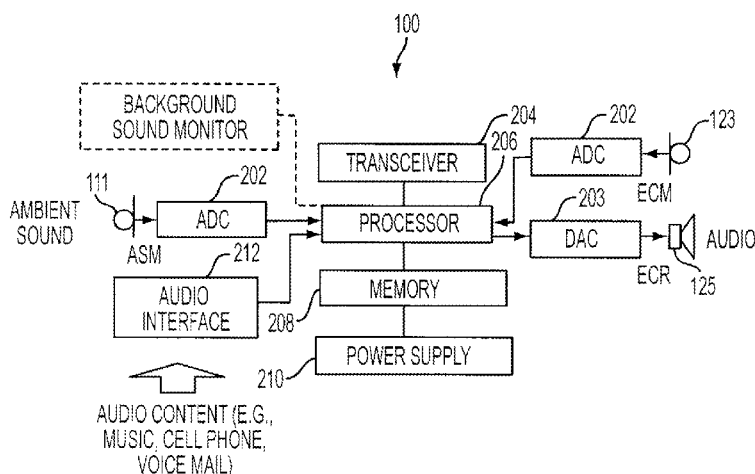
<i>H04R 25/00</i>	(2006.01)
<i>H04R 1/10</i>	(2006.01)
<i>H03G 3/32</i>	(2006.01)
<i>H04R 3/00</i>	(2006.01)
<i>H04R 3/04</i>	(2006.01)

An earpiece includes an Ambient Sound Microphone (ASM) configured to measure a background noise signal, an Ear Canal Receiver (ECR) configured to deliver audio to an ear canal, and an optional Ear Canal Microphone (ECM) configured to convert an internal sound within an ear canal of a user to an internal sound signal, and a processor operatively coupled to the ASM, the ECR and optionally the ECM. Note, internal sounds can also include residual background noise related to ambient sounds in the environment. The processor is configured to maintain a natural audio level based on a combined measurement of the background noise signal and the internal sound signal.

- (52) U.S. Cl.

CPC *H04R 1/1083* (2013.01); *H03G 3/32*
(2013.01); *H04R 1/10* (2013.01); *H04R 3/005*
(2013.01); *H04R 3/04* (2013.01); *H04R*
1/1016 (2013.01); *H04R 2410/05* (2013.01);
H04R 2420/07 (2013.01)

18 Claims, 7 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

6,023,517	A	2/2000	Ishige	
6,415,034	B1	7/2002	Hietanen	
6,567,524	B1 *	5/2003	Svean	G01H 3/14 381/314
6,728,385	B2	4/2004	Kvaloy et al.	
6,754,359	B1	6/2004	Svean et al.	
6,826,515	B2	11/2004	Bernardi	
2001/0046304	A1	11/2001	Rast	
2004/0046304	A1	3/2004	Itou et al.	
2004/0190729	A1	9/2004	Yonovitz et al.	
2005/0105750	A1	5/2005	Frohlich et al.	
2005/0111683	A1	5/2005	Chabries et al.	
2005/0254665	A1	11/2005	Vaudrey	

2005/0254667	A1	11/2005	Michael	
2006/0045282	A1	3/2006	Reber	
2006/0083388	A1	4/2006	Rothschild	
2006/0262938	A1 *	11/2006	Gauger	G10L 21/02 381/56
2007/0129828	A1	6/2007	Lee	
2007/0274531	A1	11/2007	Camp	
2008/0240458	A1	10/2008	Goldstein et al.	

OTHER PUBLICATIONS

Office Action for U.S. Appl. No. 11/966,457, filed Dec. 28, 2007, mailed Aug. 17, 2011.

Office Action for U.S. Appl. No. 12/022,826, filed Jan. 30, 2008, mailed Jul. 13, 2011.

* cited by examiner

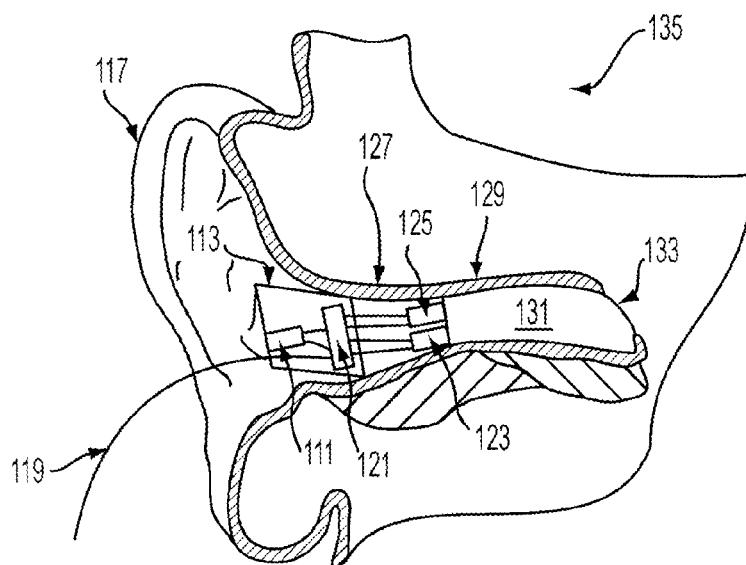


FIG. 1

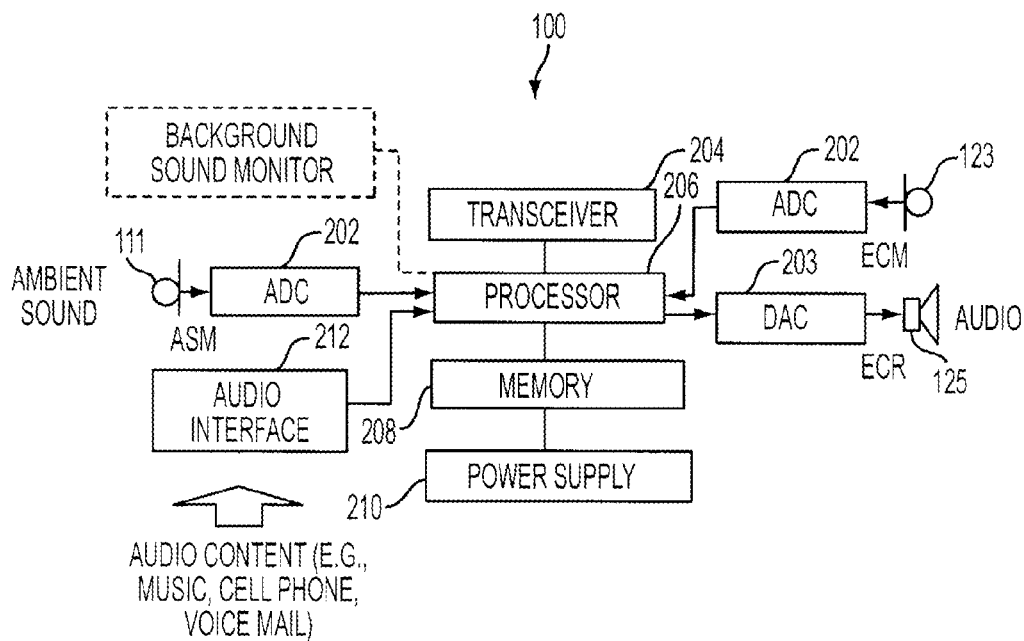
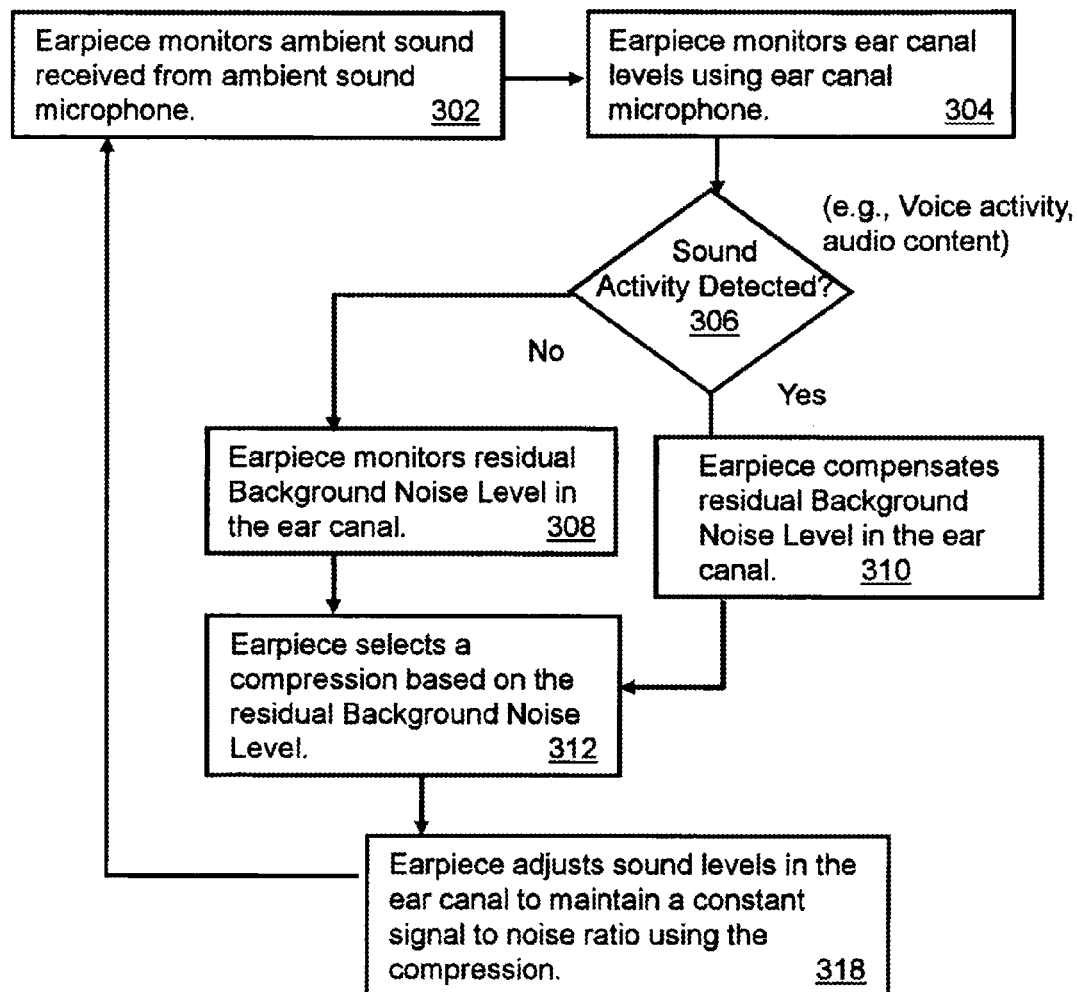
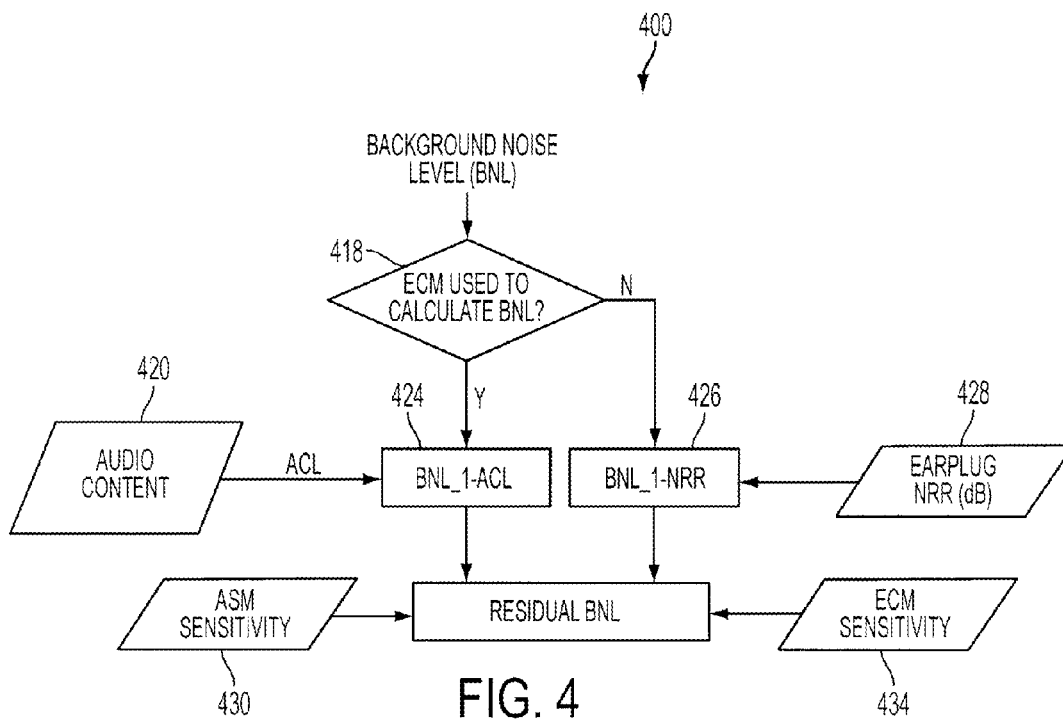
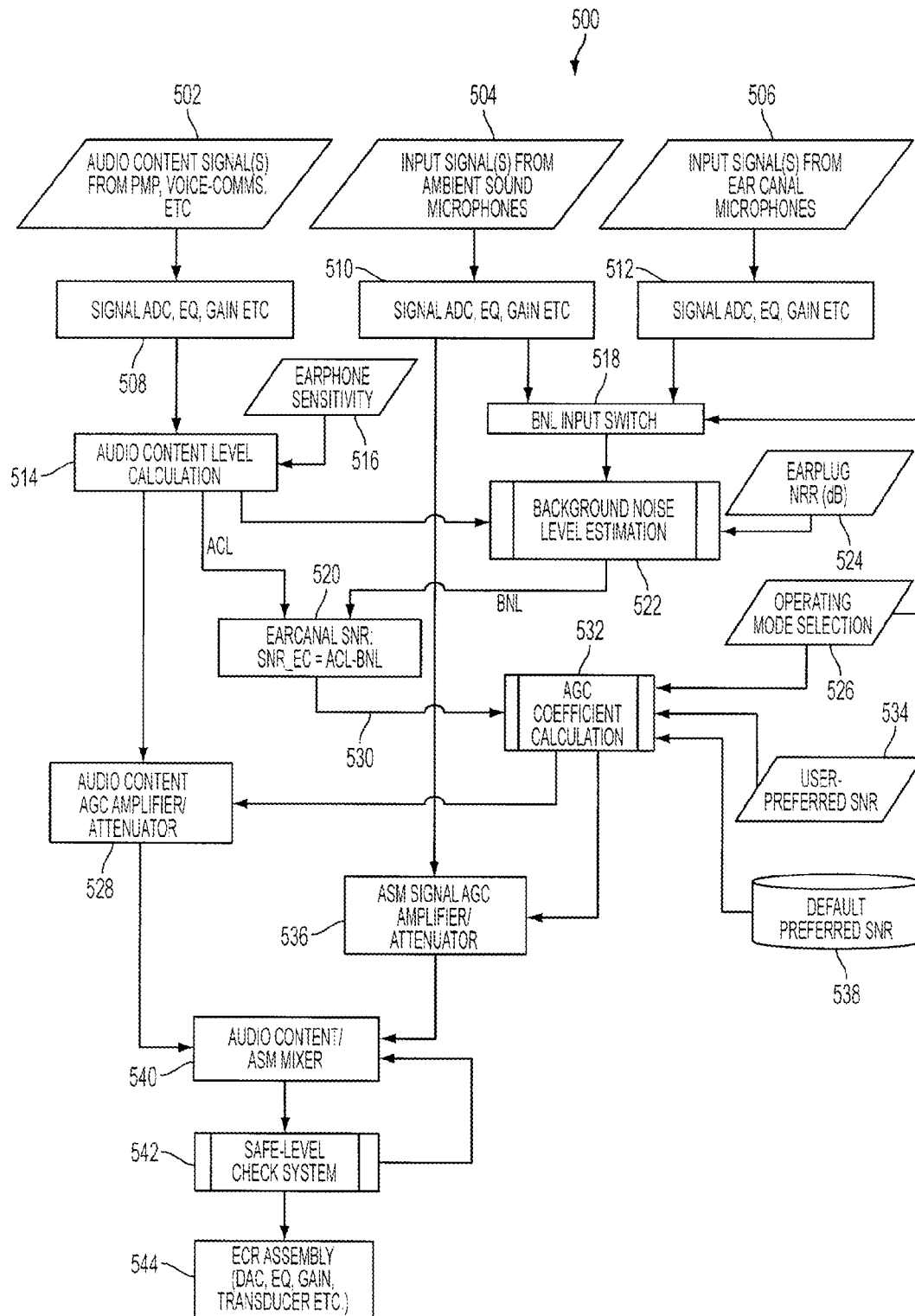


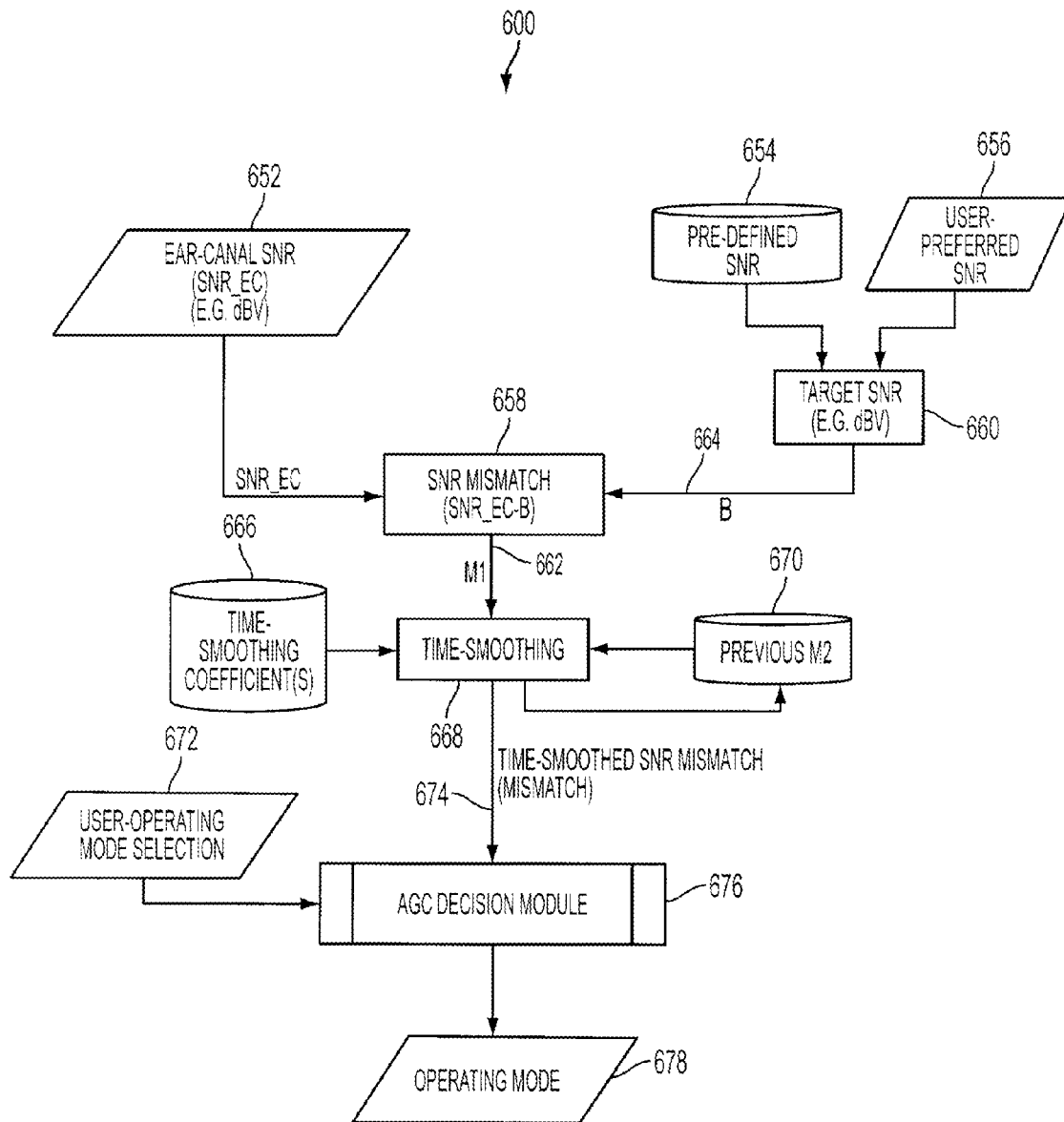
FIG. 2



300
FIG. 3







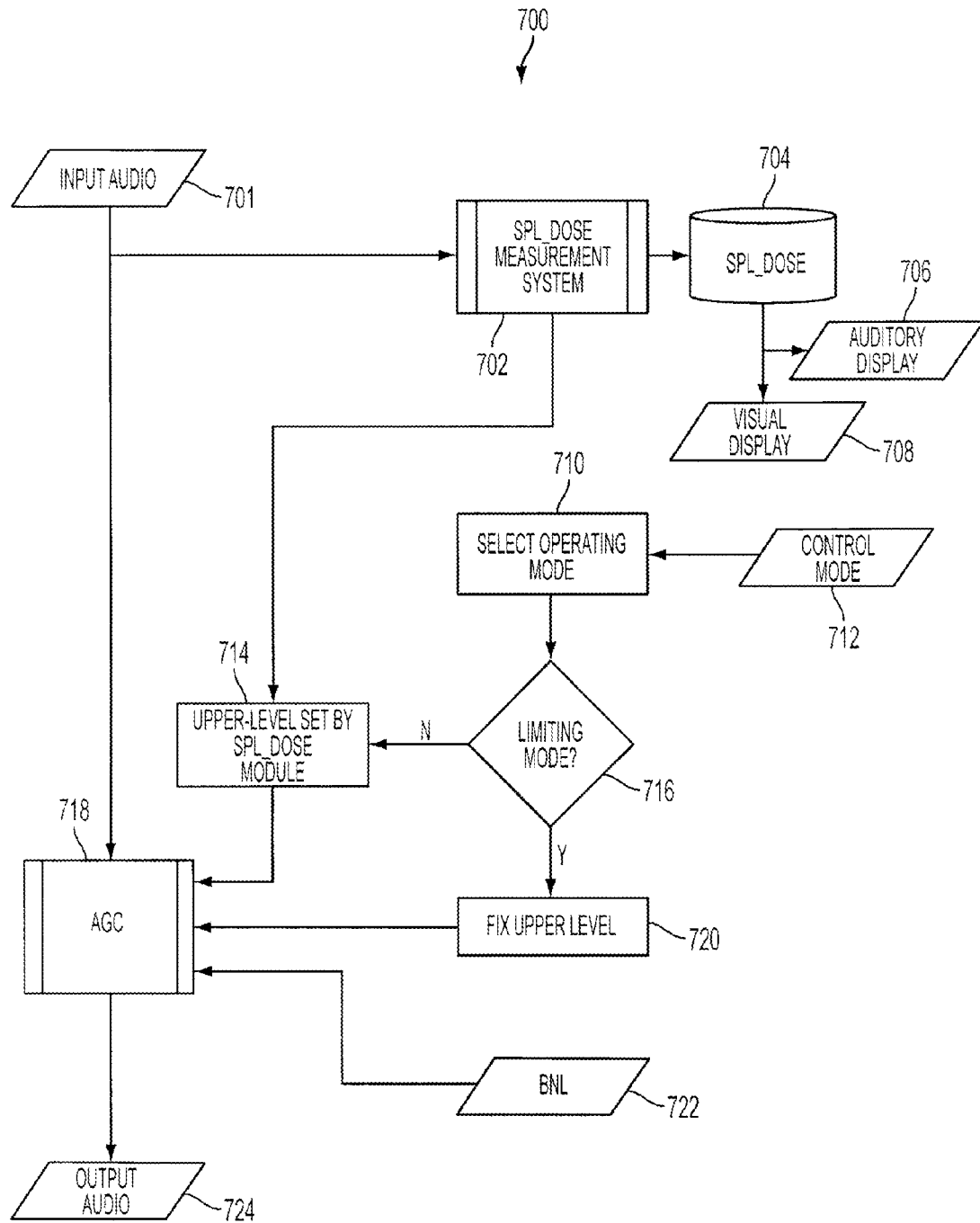


FIG. 7

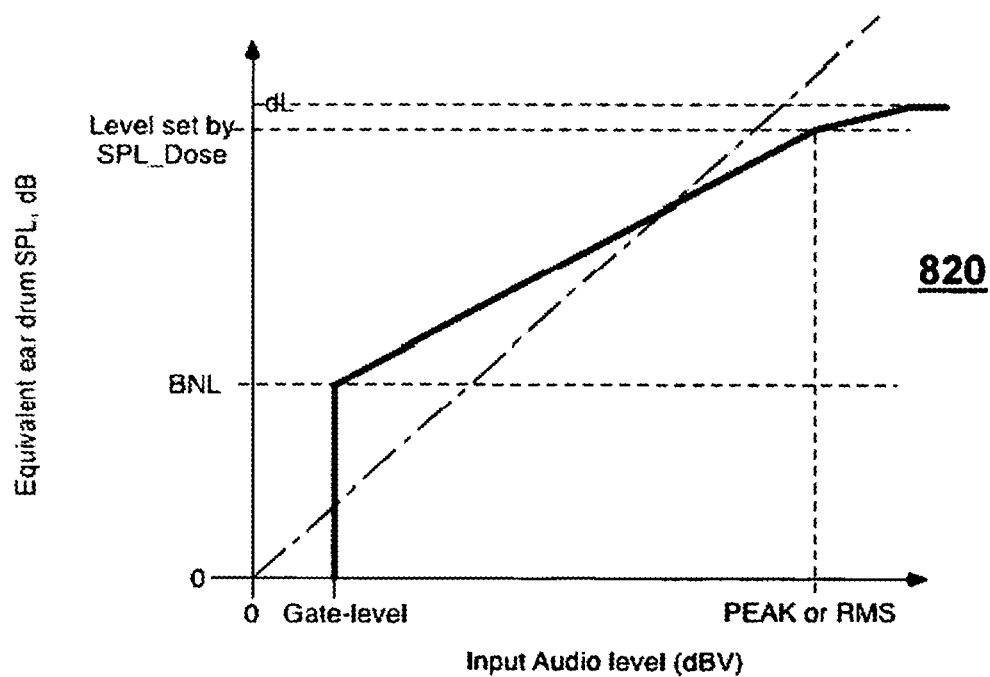
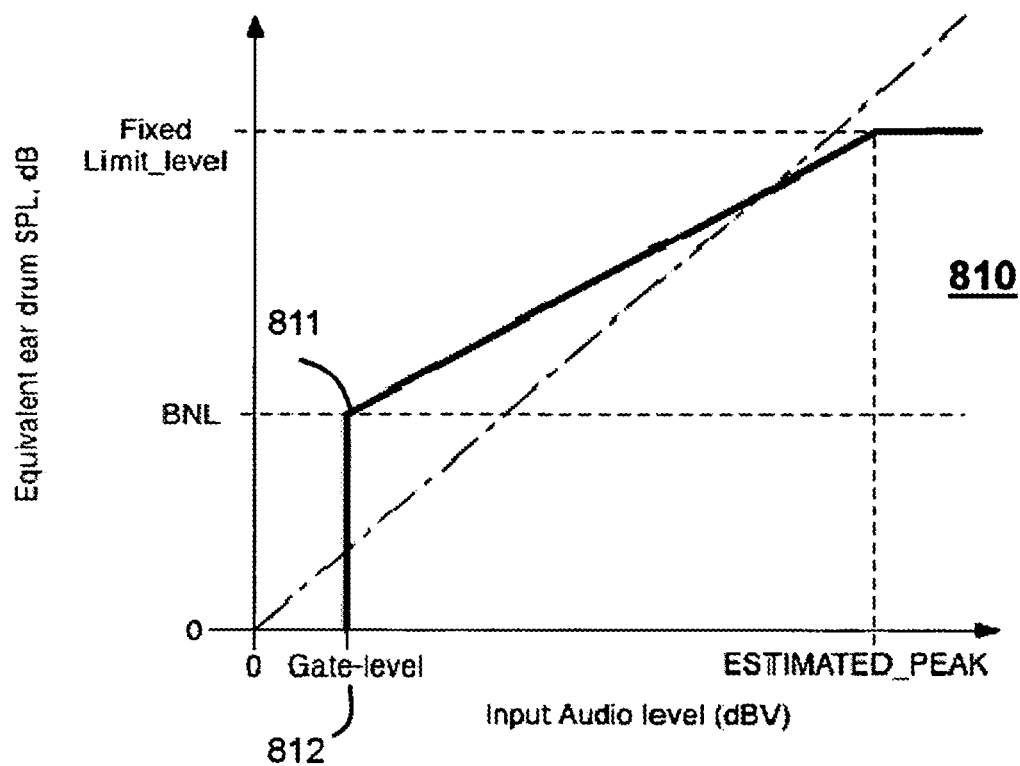


FIG. 8

1

METHOD AND DEVICE FOR BACKGROUND MITIGATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation application of U.S. patent application Ser. No. 12/165,022 filed Jun. 30, 2008, which is a Non-Provisional application of and claims the priority benefit of Provisional Application No. 60/946,834 filed on Jun. 28, 2007, the entire disclosure of which is incorporated herein by reference. This application is also related to U.S. Provisional Application No. 60/885,917 filed on Jan. 22, 2007 entitled "Method and Device for Acute Sound Detection and Reproduction", later converted to a non-provisional application 12/017,878, the entire disclosure of both of which are incorporated herein by reference. This application is also related to U.S. provisional patent application No. 60/887,165 filed on Jan. 30, 2007 entitled "Sound Pressure Level Monitoring and Notification System", later converted to a non-provisional application (application Ser. No. 12/022,826), the entire disclosure of both of which are incorporated herein by reference. This application is also related to U.S. Provisional Application No. 60/883,013 filed on Dec. 31, 2006 entitled "Method and Device for Sound Signature Detection", later converted to a non-provisional application with application Ser. No. 11/966,457, the entire disclosure of both of which are incorporated herein by reference.

FIELD

The present invention relates to a device that monitors sound directed to an occluded ear, and more particularly, though not exclusively, to an earpiece and method of operating an earpiece that monitors background noise levels and processes audio.

BACKGROUND

People that use headphones or earpieces generally do so for music enjoyment or voice communication. The user is generally immersed in the audio experience when using such devices. These devices deliver acoustic sound to the ear.

Background noises in the environment can contend with the acoustic sounds produced from these devices. As the background noise levels change, the user may need to adjust the volume to listen to their music over the background noise.

A need therefore exists for improving the sound delivery experience of headphones or earpieces.

SUMMARY

Embodiments in accordance with the present invention provide a method and device for background noise mitigation.

In a first embodiment, an earpiece can include an Ambient Sound Microphone (ASM) configured to measure a background noise level, an Ear Canal Receiver (ECR) configured to deliver audio content to an ear canal, and a processor operatively coupled to the ASM and the ECR. The processor can be configured to maintain an approximately constant ratio between an audio content level (ACL) of the audio content and a residual background noise level within the ear canal based on characteristics of the background noise level.

2

The processor can subtract an attenuation level or noise reduction rating of the earpiece from an ambient sound level of the ambient sound to estimate the residual background noise level within the ear canal. The processor can regulate ambient sound from the ASM to the ECR to maintain the approximately constant ratio. The sound produced within the ear canal upon mitigation of the background noise can be approximately the same frequency representation as the ambient sound. The processor can select a compression based on an amplitude level and a frequency content of the residual background noise. The processor can adjust sound levels in the ear canal to maintain the constant signal-to-noise ratio using the compression.

The earpiece can further comprise an ear Canal Microphone (ECM) configured to measure directly the residual background noise level within the ear canal. The processor upon detecting sound activity within the ear canal via the ECM, can update the residual background noise level to compensate for a sound level or the sound activity. The sound activity can include voice activity or audio content activity such as music.

In a second exemplary embodiment, an earpiece can include an Ambient Sound Microphone (ASM) configured to measure a background noise signal, an Ear Canal Receiver (ECR) configured to deliver audio to an ear canal, an Ear Canal Microphone (ECM) configured to convert an internal sound within an ear canal of a user to an internal sound signal, and a processor operatively coupled to the ASM, the ECR and the ECM. The processor can be configured to maintain a natural audio level based on a combined measurement of the background noise signal and the internal sound signal.

In one arrangement, the processor can estimate the residual background noise signal within the ear canal by subtracting an estimated audio content sound level (ACL) from the background noise signal. In another arrangement, the processor can estimate the residual background noise signal within the ear canal by subtracting a noise reduction rating from the background noise signal. The earpiece can estimate a sensitivity of the ASM and the ECM, and update the residual background noise signal based on characteristics of the sensitivity.

In a third exemplary embodiment, a method for audio processing suitable for use with an earpiece can include the steps of delivering audio to an ear canal, measuring a residual background noise level within the ear canal, and adjusting the audio based on characteristics of the residual background noise level to maintain a natural audio level. The method can include monitoring background noise levels external to the ear canal, and estimating the residual background noise level by subtracting an estimated audio content sound level (ACL) from the background noise level. The residual background noise level can be measured within the ear canal, and the background noise level can be measured external to the ear canal. A mixing of an ambient sound signal and an ear canal signal can be calculated, and the residual background noise level can be calculated based on the mixing.

The method can include subtracting an estimated audio content sound level (ACL) from the background noise level when an ambient sound microphone is used to measure the background noise, and/or subtracting a noise reduction rating from the background noise level when an ear canal microphone is used to measure the background noise. The method can include determining a sensitivity of an ambient

sound microphone and an ear canal microphone, and updating the residual background noise level based on characteristics of the sensitivity.

As part of the method, an audio level of audio presented to the ear canal can be adjusted to maintain an approximately constant signal to noise ratio of the audio content level to the residual background noise level within the ear canal. A delivery of ambient sound to the ear canal can be regulated to maintain an approximately constant signal to noise ratio of the audio content level to the residual background noise level within the ear canal.

The method can further include selecting a compression based on an amplitude level and a frequency content of the residual background noise, and adjusting an audio level of the audio in the ear canal to maintain a constant signal to noise ratio using the compression. The compression can be characterized by a compression curve with a knee that is a function of the residual background noise. In one arrangement, the knee can correspond to a gate level of the audio content level.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial diagram of an earpiece in accordance with an exemplary embodiment;

FIG. 2 is a block diagram of the earpiece in accordance with an exemplary embodiment;

FIG. 3 is a flowchart of a method for audio processing based on residual background noise signals suitable for use with an earpiece in accordance with an exemplary embodiment;

FIG. 4 is a flowchart for estimating residual background noise levels from a combination of measurements at an ambient sound microphone and an ear-canal microphone in accordance with an exemplary embodiment;

FIG. 5 is a flowchart of a method for background noise mitigation in accordance with an exemplary embodiment;

FIG. 6 is a flowchart of a method for maintaining constant audio content level (ACL) residual background noise level in accordance with an exemplary embodiment;

FIG. 7 is a flowchart of a method for safe level checking to monitor a total sound exposure of the listener in accordance with an exemplary embodiment; and

FIG. 8 is a plot of compression curves in accordance with an exemplary embodiment.

DETAILED DESCRIPTION

The following description of at least one exemplary embodiment is merely illustrative in nature and is in no way intended to limit the invention, its application, or uses.

Processes, techniques, apparatus, and materials as known by one of ordinary skill in the relevant art may not be discussed in detail but are intended to be part of the enabling description where appropriate, for example the fabrication and use of transducers. Additionally in at least one exemplary embodiment the sampling rate of the transducers can be varied to pick up pulses of sound, for example less than 50 milliseconds.

In all of the examples illustrated and discussed herein, any specific values, for example the sound pressure level change, should be interpreted to be illustrative only and non-limiting. Thus, other examples of the exemplary embodiments could have different values.

Note that similar reference numerals and letters refer to similar items in the following figures, and thus once an item is defined in one figure, it may not be discussed for following figures.

Note that herein when referring to correcting or preventing an error or damage (e.g., hearing damage), a reduction of the damage or error and/or a correction of the damage or error are intended.

Broadly stated, exemplary embodiments herein are directed to an earpiece and method for audio processing suitable for use with the earpiece that comprises delivering audio to an ear canal, measuring a residual background noise level within the ear canal, and adjusting the audio based on characteristics of the residual background noise level (e.g., the sound pressure level of the background noise level) to maintain a natural audio level. In one aspect, a natural audio level preserves an original volume to background noise level established by the user as originally selected by the user. In another aspect, a natural audio level preserves the fidelity and spectral content of the audio as originally selected by the user (e.g., graphic equalization) in a particular environment or context. For instance, as background noise levels change while a user is listening to music, the residual sounds in the ear canal change; the earpiece automatically adjusts the volume level to a preferred setting to maintain a natural music signal level to residual background noise level within the ear canal. In one case, the preferred setting can be automatically set when the user makes the music selection and adapted thereafter.

At least one exemplary embodiment of the invention is directed to an earpiece for background noise mitigation. Reference is made to FIG. 1 in which an earpiece device, generally indicated as earpiece **100**, is constructed in accordance with at least one exemplary embodiment of the invention. As illustrated, earpiece **100** depicts an electro-acoustical assembly **113** (also referred to herein as assembly **113**) for an in-the-ear (in-ear) acoustic assembly, as it would typically be placed in the ear canal **131** of a user **135**. The earpiece **100** can be an in the ear earpiece, behind the ear earpiece, receiver in the ear, open-fit device, or any other suitable earpiece type. The earpiece **100** can be partially or fully occluded in the ear canal, and is suitable for use with users having healthy or abnormal auditory functioning.

Earpiece **100** includes an Ambient Sound Microphone (ASM) **111** to capture ambient sound, an Ear Canal Receiver (ECR) **125** to deliver audio to an ear canal **131**, and an Ear Canal Microphone (ECM) **123** to capture internal sounds within the ear canal and also assess a sound exposure level within the ear canal. The earpiece **100** can partially or fully occlude the ear canal **131** to provide various degrees of acoustic isolation. The assembly is designed to be inserted into the user's ear canal **131**, and to form an acoustic seal with the walls **129** of the ear canal at a location **127** between the entrance **117** to the ear canal **131** and the tympanic membrane (or eardrum) **133**. Such a seal is typically achieved by means of a soft and compliant housing of assembly **113**. Such a seal is pertinent to the performance of the system in that it creates a closed cavity of ear canal **131** (also referred to herein as closed cavity **131** or ear canal cavity **131**) of approximately 5 cc between the in-ear assembly **113** and the tympanic membrane **133**. As a result of this seal, the ECR (speaker) **125** is able to generate a full range bass response when reproducing sounds for the user. This seal also serves to significantly reduce the sound pressure level at the user's eardrum **133** resulting from the sound field at the entrance to the ear canal **131**. This seal is also the basis for the sound isolating performance of the electro-acoustical assembly **113**.

Located adjacent to the ECR **125**, is the ECM **123**, which is acoustically coupled to the (closed) ear canal cavity **131**. One of its functions is that of measuring the sound pressure

5

level in the ear canal cavity **131** as a part of testing the hearing acuity of the user as well as confirming the integrity of the acoustic seal and the working condition of itself and the ECR **125**. The ECM **123** can also be used for capturing voice that is resonant within the ear canal when the user is speaking to permit voice communication.

The ASM **111** is housed in an assembly **113** and monitors sound pressure at the entrance to the occluded or partially occluded ear canal. The ASM **111** can also be used to capture the user's voice externally for permitting voice communication. All transducers shown can receive or transmit audio signals to a processor **121** that undertakes audio signal processing and provides a transceiver for audio or voice via the wired or wireless communication path **119**.

The earpiece **100** can actively monitor a sound pressure level both inside and outside an ear canal and enhance spatial and timbral sound quality while maintaining supervision to ensure safe sound reproduction levels. The earpiece **100** in various exemplary embodiments can conduct listening tests, filter sounds in the environment, monitor warning sounds in the environment, present notification based on identified warning sounds, maintain constant audio content to ambient sound levels, and filter sound in accordance with a Personalized Hearing Level (PHL).

Referring to FIG. 2, a block diagram of the earpiece **100** in accordance with an exemplary embodiment is shown. As illustrated, the earpiece **100** can include a processor **206** operatively coupled to the ASM **111**, ECR **125**, and ECM **123** via one or more Analog to Digital Converters (ADC) **202** and Digital to Analog Converters (DAC) **203**. The processor **206** can measure ambient sounds in the environment received at the ASM **111** and internal sounds captured at the ECM **123**. Ambient sounds correspond to sounds within the environment such as the sound of traffic noise, street noise, conversation babble, or any other acoustic sound.

Ambient sounds can also correspond to industrial sounds present in an industrial setting, such as, factory noise, lifting vehicles, automobiles, and robots. Internal sounds can correspond to sound contained within the ear canal **131** such as spoken voice or audio content delivered by way of the ECR **125**. The internal sounds can also include residual background noise related to ambient sounds in the environment; for example, high level sounds that leak around the ear seal at location **127** and enter the ear canal **131**. The processor **206** can monitor the ambient sound captured by the ASM **111** for sounds in the environment, such as an abrupt high energy sound corresponding to an on-set of a warning sound (e.g., bell, emergency vehicle, security system, etc.), siren (e.g., police car, ambulance, etc.), voice (e.g., "help", "stop", "police", etc.), or specific noise type (e.g., breaking glass, gunshot, etc.).

The processor **206** can utilize computing technologies such as a microprocessor, Application Specific Integrated Chip (ASIC), and/or digital signal processor (DSP) with associated storage memory **208** such as Flash, ROM, RAM, SRAM, DRAM or other like technologies for controlling operations of the earpiece device **100**. The memory **208** can store program instructions for execution on the processor **206** as well as captured audio processing data.

The memory **208** can also store program instructions for execution on the processor **206** as well as captured audio processing data and filter coefficient data. The memory **208** can be off-chip and external to the processor **206**, and include a data buffer to temporarily capture the ambient sound and the internal sound, and a storage memory to save from the data buffer the recent portion of the history in a

6

compressed format responsive to a directive by the processor **206**. The data buffer can be a circular buffer that temporarily stores audio sound at a current time point to a previous time point. It should also be noted that the data buffer can in one configuration reside on the processor **206** to provide high speed data access. The storage memory **208** can be non-volatile memory such as SRAM to store captured or compressed audio data.

The earpiece **100** can include an audio interface **212** operatively coupled to the processor **206** to receive audio content, for example from a media player or cell phone, and deliver the audio content to the processor **206**. The processor **206** responsive to detecting acute sounds can adjust the audio content and pass the acute sounds directly to the ear canal. For instance, the processor can lower a volume of the audio content responsive to detecting an acute sound for transmitting the acute sound to the ear canal. The processor **206** can also actively monitor the sound exposure level inside the ear canal and adjust the audio to within a safe and subjectively optimized listening level range.

The earpiece **100** can further include a transceiver **204** that can support singly or in combination any number of wireless access technologies including without limitation Bluetooth™, Wireless Fidelity (WiFi), Worldwide Interoperability for Microwave Access (WiMAX), and/or other short or long range communication protocols. The transceiver **204** can also provide support for dynamic downloading over-the-air to the earpiece **100**. It should be noted also that next generation access technologies can also be applied to the present disclosure.

The power supply **210** can utilize common power management technologies such as replaceable batteries, supply regulation technologies, and charging system technologies for supplying energy to the components of the earpiece **100** and to facilitate portable applications. A motor (not shown) can be a single supply motor driver coupled to the power supply **210** to improve sensory input via haptic vibration. As an example, the processor **206** can direct the motor to vibrate responsive to an action, such as a detection of a warning sound or an incoming voice call.

The earpiece **100** can further represent a single operational device or a family of devices configured in a master-slave arrangement, for example, a mobile device and an earpiece. In the latter exemplary embodiment, the components of the earpiece **100** can be reused in different form factors for the master and slave devices.

FIG. 3 is a flowchart of a method **300** for background noise mitigation in accordance with an exemplary embodiment. The method **300** can be practiced with more or less than the number of steps shown and is not limited to the order shown. To describe the method **300**, reference will be made to components of FIG. 2, although it is understood that the method **300** can be implemented in any other manner using other suitable components. The method **300** can be implemented in a single earpiece, a pair of earpieces, headphones, or other suitable headset audio delivery devices.

The method **300** can start in a state wherein the earpiece **100** has been inserted and powered on. As shown in step **302**, the earpiece **100** can monitor the environment for ambient sounds received at the ASM **111**. Ambient sounds correspond to sounds within the environment such as the sound of traffic noise, street noise, conversation babble, or any other acoustic sound. Ambient sounds can also correspond to industrial sounds present in an industrial setting, such as factory noise, lifting vehicles, automobiles, and robots to name a few.

Although the earpiece **100** when inserted in the ear can partially occlude the ear canal, the earpiece **100** may not completely attenuate the ambient sound. During the monitoring of ambient sounds in the environment, the earpiece **100** also monitors ear canal levels via the ECM **123** as shown in step **304**. The passive aspect of the physical earpiece **100**, due to the mechanical and sealing properties, can provide upwards of a 22-26+dB noise reduction. However, portions of ambient sounds higher than 26 dB may still pass through the earpiece **100** into the ear canal generating residual sound in the ear canal.

At step **306**, a determination of whether sound activity is detected can be made. Sound activity can correspond to audio content (e.g., music, voice mail, voice), and/or spoken voice (i.e., when the user of the earpiece **100** is speaking). Sound within the ear canal **131** can also be provided via the audio interface **212**. The audio interface **212** can receive the audio content from at least one among a portable music player, a cell phone, and a portable communication device. The audio interface **212** responsive to user input can direct sound to the ECR **125**. For instance, a user can elect to play music through the earpiece **100** which can be audibly presented to the ear canal **131** for listening. The user can also elect to receive voice communications (e.g., cell phone, voice mail, messaging) via the earpiece **100**. For instance, the user can receive audio content for voice mail or a phone call directed to the ear canal via the ECR **125**.

If at step **306**, sound activity (e.g., music, cell phone, spoken voice) is not detected, the earpiece **100** monitors residual background noise level in the ear canal at step **308**. Residual background noise is resident in the ear canal and can be heard by the user. The residual background noise (sound) can be a residue of the background sounds in the ambient environment that are not completely attenuated by the earpiece **100**. For example, a loud explosion, car horn, siren, snoring, or crash sound in the environment may pass through (passively) the earpiece **100** as residual sound and be heard by the user wearing the earpiece. The processor **206** by way of the ECM **123** can monitor the ear canal for residual background noises corresponding to ambient background noises in the environment.

The processor **206** can distinguish residual background noise from sound activity such as audio content by way of configuration logic. For instance, in the case of detecting audio content, the processor **206** is aware whether it is delivering audio content to the ECR **125**. The control logic establishes whether the processor **206** is actively playing sound (e.g., music), or actively receiving a phone call, for example, from audio data and/or information that is provided from the audio interface **212**. Configuration logic does not include analyzing acoustic sound waves within the ear canal to discriminate among differing sound patterns.

The processor **206** can however discriminate between spoken voice (when the user is speaking) and residual background noise based on characteristics of the user's voice, such as, level, frequency, and duration. For instance, upon detecting periods of up and down energy fluctuations within certain time interval durations and within certain frequency ranges, the processor **206** can flag a presence of voice-speech is characterized by periods of energy fluctuations over time (e.g. words or phrases). The processor **206** can also include voice activity detection logic to assess whether internal sounds captured in the ear canal have characteristics (e.g., level, pitch, energy, onset, etc) that correspond to spoken voice for detecting sound activity. This permits the processor **206** to discriminate between spoken voice and residual background noises in the ear canal.

If at step **306** sound activity is detected, the earpiece compensates the residual background noise level in the ear canal at step **310**. For instance, as discussed ahead, the earpiece can account for an audio content level or a noise reduction rating of the earpiece **100**. In one case, the processor **206** can estimate (or update) the residual background noise signal within the ear canal by subtracting an estimated audio content sound level (ACL) from the background noise signal. Alternatively, or in combination, the processor **206** can estimate (or update) the residual background noise signal within the ear canal by subtracting a noise reduction rating from the background noise signal.

At step **312**, the earpiece **100** selects a compression based on the residual background noise level. The compression can be a time domain or a frequency domain transformation that is applied to the audio content to amplify or attenuate portions of the audio content waveforms. FIG. **8** illustrates a first compression curve **810** and a second compression curve **820** that are a function of the residual background noise level. More specifically, the compression is characterized by a compression curve with a knee **811** that is a function of the residual background noise level (BNL). The knee **811** can correspond to a gate level **812** of the audio content level.

Returning back to FIG. **3**, the earpiece **100** upon selecting a compression adjusts sound levels in the ear canal to maintain a constant signal to noise ratio as shown in step **318**. The processor **206** can thus, in determination of the residual background noise measured within the ear canal, mitigate the effects of the background noise by adjusting the volume level and frequency response of the audio content delivered to the ear canal. Alternatively, or in combination, the processor **206** can also regulate the throughput of ambient sound from the ASM **111** to the ECM **123** to maintain a constant signal to noise ratio.

The method **300** can continue back to step **302** and **304** to monitor ambient sounds in the environment and residual background noise levels in the ear canal, respectively.

FIG. **4** is a flowchart of a method **400** for compensating the residual background noise level. The method **400** relates to method step **310** of FIG. **3** for compensating the residual background noise level based on a determination of sound activity. The method **400** can be practiced with more or less than the number of steps shown and is not limited to the order shown.

Briefly, method **400** receives as input a background noise estimate from the ambient sound signal from ASM **111** and/or the internal sound signal from the ECM **123**. The method **400** updates the residual background noise level depending on which microphone (ASM or ECM) is used to measure the residual noise. This is done to compensate for differences in location, sensitivity, and configuration of the earpiece **100** operating modes and component configurations (e.g., ASM **111**, ECM **123**, ECR **125**).

If at step **418**, it is determined that the ECM **123** was used to calculate the Background Noise Level (BNL), the processor **206** at step **424** subtracts off an audio content level (ACL) of the audio content **420** to update the residual background noise level measured within the ear canal. (Subtracts refers to removing the contribution, though the operation may be a multiplication or division operation; sound levels can be expressed as SPL ratios (division) which in dB is a subtraction.) Recall, that the audio interface **212** can deliver music to the processor **206** and that music is played out the ECR **125**. The processor **206** at step **424** accounts for the level of the audio content when assessing

the residual background noise levels when sound activity is detected by removing the audio content level (see FIG. 3).

In one arrangement, the processor 206 can apply an ear-canal transfer function to the audio content delivered to the ECR 125 to obtain an estimate of the audio content level. Moreover, the processor in periods of non-spoken activity can update the transfer function to improve the estimate of the transfer function. Upon estimating the audio content level, the processor can update the residual background noise levels by subtracting off the estimated audio content level. In this manner, the ECM 123 can be used alone to provide an estimate of the residual background noise within the ear canal.

If at step 418 it is however determined that the ASM 111 was used to calculate the background noise level, the processor 206 at step 426 subtracts a noise reduction rating (NRR) 428 from the background noise level to estimate the residual background noise level within the ear canal. Recall, the sealing aspect of the earpiece 100 provides a degree of acoustic isolation expressed as a noise reduction rating (NRR). In this manner, the processor can monitor the ASM 111 to provide an estimate of the residual background noise within the ear canal.

As shown in steps 430 and 434, the ASM sensitivity and ECM sensitivity can be respectively taken into account when calculating the residual background noise level. The ASM and ECM sensitivity can be measured through scheduled or random calibration tests administered by the earpiece 100. For instance, to evaluate the ECM sensitivity, the processor 206 can direct the ECR 125 to emit a conditioned test tone and simultaneously listen to the generated test tone via the ECM 123. The processor 206 can compare the frequency response of the captured test tone with a calibrated frequency response to determine any offset in sensitivity. When the earpiece is removed from the ear, the processor, upon detection by the earpiece 100 or from manual intervention, can direct the ECR 125 to emit a conditioned test tone and simultaneously listen to the generated test tone via the ASM 111. The earpiece 100 is removed to permit passage of sound from the ECR 125 to the ASM 111 as shown in FIG. 1. Similarly, the processor can compare the frequency response of the captured test tone with a calibrated frequency response to determine any offset in sensitivity.

The residual background noise resident in the ear canal can also be estimated from a combination of the ASM 111 and ECM 123 measurements. Accordingly, the method 400 can further include determining a mixing of an ambient sound signal and the internal (e.g. ear canal) signal, and calculating the residual background noise level based on the mixing. Upon determining the compensation levels, the method 400 can proceed to determine compression curves (see FIG. 8) based on characteristics of the residual background noise level. The compression curves (810 and 820) can be implemented by various types of filters (FIR, IIR, parametric, bi-quad, etc.) Upon selecting a compression, the earpiece 100 adjusts an audio level of audio presented to the ear canal to maintain an approximately constant signal to noise ratio of the audio content level to the residual background noise level within the ear canal.

FIG. 5 is a flowchart of a method 500 for maintaining constant audio content level (ACL) to residual background noise level (BNL). The method 500 can be practiced with more or less than the number of steps shown and is not limited to the order shown. To describe the method 500, reference will be made to components of FIG. 2, although it is understood that the method 500 can be implemented in

any other manner using other suitable components. The method 500 can be implemented in a single earpiece, a pair of earpieces, headphones, or other suitable headset audio delivery devices.

Briefly, FIG. 5 describes a method 500 for Constant Signal-to-Noise Ratio (CSNRS) based on measured residual background noise within the ear canal. At step 504 an input signal is captured from the ASM 111 and processed at step 510 (e.g. ADC, EQ, gain). Similarly, at step 506 an input signal from the ECM 123 is captured and processed at step 512. The method 500 also receives as input an Audio Content signal 502, e.g. a music audio signal from a portable Media Player or mobile-phone, which is processed with analog and digital signal processing as shown in step 508. An Audio Content Level (ACL) is determined at step 514 that incorporates at step 516 an earpiece (earphone) sensitivity, and returns a dBV value.

In at least one exemplary embodiment, method 500 calculates a RMS value over a window (e.g. the last 100 ms). The RMS value can be first weighted with a first weighting coefficient and then averaged with a weighted previous level estimate. The ACL is converted to an equivalent SPL value (ACL), which can use either a look-up-table or algorithm to calculate the ear-canal SPL of the signal if it was reproduced with the ECR 125. To calculate the equivalent ear canal SPL, the sensitivity of the ear canal receiver can be factored in during processing.

At step 522 the BNL is estimated using inputs from either or both the ASM signal at step 504, and/or the ECM signal at step 506. These signals are selected using the BNL input switch at step 518, which may be controlled automatically or with a specific user-generated manual operation at step 526. The earpiece 100 noise reduction rating (NRR) can also be taken into account at step 524 when estimating the BNL, for example, by subtracting the dB value of the NRR from the BNL. The Ear-Canal SNR is calculated at step 520 by differencing the ACL from step 514 and the BNL from step 522 and the resulting SNR 530 is passed to the method step 532 for AGC coefficient calculation. The AGC coefficient calculation calculates gains for the Audio Content signal and ASM signal from the Automatic Gain Control steps 528 and 536 (for the Audio Content and ASM signals, respectively). A user preferred SNR can also be taken into account when calculating the AGC coefficients as illustrated by step 534. Alternatively a default preferred SNR can be used instead at step 538. After the ASM signal and Audio content signal have been processed by the AGC's 528 and 536, the two signals are mixed at step 540.

At step 542, a safe-level check determines if the resulting mixed signal is too high in level, if it were reproduced with the ECR 125 as shown in block 544. The safe-level check can use information regarding the user's listening history to determine if the user's sound exposure is such that it may cause temporary or permanent hearing threshold shift. If such high levels are measured, then the safe-level check reduces the signal level of the mixed signals via a feedback path to step 540. The resulting audio signal generated after step 542 is then reproduced with the ECR 125.

FIG. 6 is a flowchart of a method 600 for maintaining constant signal to noise ratio based on automatic gain control (AGC). The method 600 can be practiced with more or less than the number of steps shown and is not limited to the order shown. To describe the method 600, reference will be made to components of FIG. 2, although it is understood that the method 600 can be implemented in any other manner using other suitable components. The method 600

11

can be implemented in a single earpiece, a pair of earpieces, headphones, or other suitable headset audio delivery devices.

Method 600 describes calculation of AGC coefficients. The method 600 receives as its inputs an Ear Canal SNR 652 and a target SNR 660 to provide a SNR mismatch 658. The target SNR is chosen from a pre-defined SNR 654, sorted in computer memory or a manually defined SNR 656. At step 658, a difference is calculated between the actual ear-canal SNR (SNR-EC) and the target SNR (B) 664 to produce the mismatch 662. The mismatch level 662 is smoothed over time at step 668, which uses a previous mismatch (M2) 670 that is weighted using single or multiple weighting coefficients 666, to give a new time-smoothed SNR mismatch 674. Depending on the magnitude of this mismatch, various operating modes 678 can be invoked, for example, by user operating mode 672 or as described by the AGC decision module 676.

FIG. 7 illustrates an exemplary embodiment of a “safe level checking” system 700 which includes a system 702 to monitor the total sound exposure of the listener (SPL_Dose measurement system). The safe level checking system 700 can receive input audio 701 from either the audio interface 212, ambient sound from the ASM 111, internal sound within the ear canal via the ECM 123, or sound produced from the ECR 125 and captured by the ECM 123.

The safe level checking system 700 can control the reproduction level of the ECR 125 signal when generating the output audio 724 to reduce the chance of permanent hearing damage to the user. The safe level checking system 700 can select compression curves (FIG. 8) (based on BNL 722) and/or automatic gain coefficients (AGC) 718 to adjust the input audio 701 to within safe listening output audio 724.

The SPL_Dose measurement system 702 keeps a record of the total sound exposure to the listener (measured or estimated at the eardrum). An SPL_Dose 704 is calculated, that is a percentage value of the running personal exposure dose (i.e. the dose is not reset every day, but carries on when the earphones are worn), where 100% corresponds to a maximum daily dose (e.g. according to OSHA recommendations) and a value greater than 100% indicates that the user may be at risk of permanent hearing damage.

The SPL_Dose value 704 is communicated to the user with either or both visual means 708 (e.g. a read-out of the dose on a display on a mobile communications device or Portable Media Player (PMP) screen) or with auditory means 706 (e.g. a voice message indicating the SPL_Dose, or a voice message or non-voice message indicating when the SPL_Dose is a particular value, e.g. 75% and 100%). In at least one exemplary embodiment, the SPL_Dose is converted to a time value indicating the total remaining time that the user can continue to listen to reproduced audio content at a given average SPL value (e.g. an SPL_value approximately equal to the recent average SPL value generated by reproduced audio content). The user can be informed of this time value using either or both visual or/and sound means, as with the SPL_Dose.

In another exemplary embodiment, an operating mode 710 is selected either manually using interface means 712 (e.g. via a keypad entry on a PMP or mobile phone) or automatically, for instance with non-user changeable means depending on regional laws, to invoke a fixed maximum reproduction limit 720. This maximum limit may be a peak or RMS dB SPL value, approximating the SPL measured at the eardrum. When the “limiting mode” 716 is selected (i.e. either automatically or manually) then the AGC 718 that processes the input audio 701 (e.g. the mix of audio content

12

from a media player and audio from the ASM and/or ECM) is updated so that the maximum peak or RMS value of audio reproduced with the ECR is equal to the predetermined maximum limit value. In another exemplary embodiment, when the limiting mode is not selected, the upper value of the AGC is set 714 by the SPL_Dose system 700, e.g. to allow the user to listen to audio content at a predetermined level for a predetermined length of time to reduce the likelihood of permanent hearing damage.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all modifications, equivalent structures and functions of the relevant exemplary embodiments. Thus, the description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the exemplary embodiments of the present invention. Such variations are not to be regarded as a departure from the spirit and scope of the present invention.

The invention claimed is:

1. An earpiece, comprising:

an Ambient Sound Microphone (ASM) configured to measure a background noise signal of an ambient field; an Ear Canal Receiver (ECR) configured to deliver audio to an ear; and

a processor operatively coupled to the ASM and the ECR, where the processor is configured to:

maintain a natural audio level based on a combined measurement of a background noise signal and an internal sound signal;

determine a residual background noise level within the ear canal based on at least one of the background noise level of the ambient sound or a measured ear canal background noise level within the ear canal using an ear canal microphone;

determine an ear canal signal to noise ratio (SNR) between the audio content level of the audio and the residual background noise level;

determine a mismatch between the ear canal SNR and a target SNR; and

adjust a gain applied to at least one of the audio or the ambient sound based on the mismatch such that an approximately constant SNR is maintained between the audio content level and the residual background noise level within the ear canal.

2. The earpiece of claim 1, further comprising an Ear Canal Microphone (ECM) operatively coupled to the processor and configured to convert an internal sound within the ear canal to the internal sound signal.

3. The earpiece of claim 1, wherein the Ambient Sound Microphone is within a media player or cell phone operatively coupled to the processor.

4. The earpiece of claim 1, wherein the Ambient Sound Microphone measures the background noise signal of the ambient sound at an entrance to an occluded ear canal or to a partially occluded ear canal.

5. The earpiece of claim 1, wherein the processor maintains the natural audio level based on maintaining a constant signal to noise ratio which is further based on automatic gain control.

6. The earpiece according to claim 1, wherein the processor estimates a residual background noise signal within

13

the ear canal by subtracting an estimated audio content sound level (ACL) from a background noise level of the background noise signal.

7. The earpiece according to claim 1, wherein the processor

estimates a residual background noise signal within the ear canal by subtracting a noise reduction rating from the background noise signal.

8. An earpiece, comprising:

an Ambient Sound Microphone (ASM) configured to measure a background noise signal of an ambient field; an Ear Canal Receiver (ECR) configured to deliver audio to an ear; and

a processor operatively coupled to the ASM and ECR, where the processor is configured to:

maintain a natural audio level based on a combined measurement of a background noise signal and an internal sound signal;

estimates a sensitivity of the ASM and the ECM; and updates a residual background noise signal based on characteristics of the sensitivity.

9. The earpiece according to claim 1, wherein the internal sound signal comprises an input audio signal.

10. A method for audio processing, the method comprising the steps of:

delivering audio to an ear canal using an ear canal receiver;

estimating a residual background noise level within the ear canal using an ambient microphone or an ear canal microphone;

adjusting the audio based on characteristics of the residual background noise level to maintain a natural audio level;

determining a first sensitivity of the ambient sound microphone and a second sensitivity of the ear canal microphone; and

updating the residual background noise level based on characteristics of the first and second sensitivity.

11. The method according to claim 10, further comprising:

monitoring a background noise level external to the ear canal; and

14

estimating an updated residual background noise level by subtracting an estimated audio content sound level (ACL) from the background noise level, wherein the background noise level is measured external to the ear canal.

12. The method according to claim 10, further comprising:

determining a mixing of an ambient sound signal and an ear canal signal; and calculating an updated residual background noise level based on the mixing.

13. The method according to claim 10, further comprising:

subtracting an estimated audio content sound level (ACL) from the background noise level when the ear canal microphone is used to measure the background noise.

14. The method according to claim 12, further comprising:

adjusting an audio level of audio presented to the ear canal to maintain an approximately constant signal to noise ratio of an audio content level to the residual background noise level within the ear canal.

15. The method according to claim 12, further comprising:

regulating a delivery of ambient sound to the ear canal to maintain an approximately constant signal to noise ratio of an audio content level to the residual background noise level within the ear canal.

16. The method according to claim 12, further comprising:

selecting a compression based on an amplitude level and a frequency content of the residual background noise; and adjusting an audio level of the audio in the ear canal to maintain a constant signal to noise ratio using the compression.

17. The method according to claim 10, wherein the method further maintains a record of a total sound exposure delivered.

18. The method according to claim 10, wherein the method further maintains a record of a total sound exposure and presents a predetermined sound pressure level dose value.

* * * * *